

Fringe Science: Defringing CCD Images with Neon Lamp Flat Fields

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ABSTRACT

Fringing in CCD images is troublesome from the aspect of photometric quality and image flatness in the final reduced product. Additionally, defringing during calibration requires the inefficient use of time during the night to collect and produce a “supersky” fringe frame. The fringe pattern observed in a CCD image for a given near-IR filter is dominated by small thickness variations across the detector with a second order effect caused by the wavelength extent of the emission lines within the bandpass which produce the interference pattern. We show that essentially any set of emission lines which generally match the wavelength coverage of the night sky emission lines within a bandpass will produce an identical fringe pattern. We present an easy, inexpensive, and efficient method which uses a neon lamp as a flat field source and produces high S/N fringe frames to use for defringing an image during the calibration process.

Subject headings: Astronomical Techniques – Data Analysis and Techniques

1. Introduction

Fringing in CCD images occurs due to an interference effect similar to Newton’s Rings¹. The production of constructive and destructive interference patterns can cause substantial quantum efficiency variations in thinned CCDs as long wavelength light is multiply reflected between the front and back surfaces. Fringing begins to be an issue for CCDs when the absorption depth within the silicon becomes comparable to the thickness of the CCD. This occurs for optical wavelengths of ~ 700 nm or longer for which the light is internally reflected several times before finally being absorbed (Lesser 1990; Howell 2006).

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¹The observed phenomenon of Newton’s Rings was first described by Robert Hooke in his 1664 book *Micrographia* although it is named for Isaac Newton, who was the first to quantitatively analyze the phenomena.

During the commissioning of the upgraded Kitt Peak 4-m telescope Mosaic 1.1 imager in the fall of 2010, we produced neon lamp dome flats capable of fringe removal during the image reduction process. The 8K x 8K Mosaic 1.1 imager (Sawyer et al., 2010) consists of eight 2048 x 4096 e2v CCD44-82 deep depletion (DD) CCDs placed together in a single mosaiced focal plane. The e2v CCDs have low noise and deep pixel wells ($\geq 200,000$ electrons) and are subject to fringing in the R, I, and z bands. Details of the Mosaic 1.1 imager can be found at the Kitt Peak National Observatory web site².

To eliminate the need to use valuable observing time during the night to collect a set of deep sky exposures in order to produce a “supersky” fringe frame, we used afternoon flat field exposures of a neon lamp to obtain high S/N, fringe frames. The fringe pattern produced in a CCD image is shown to consist of an average pattern from all the emission lines present within a given filter bandpass, thus the neon emission line source (Ne lamp) provides a match to the fringe pattern produced by night sky emission on a filter by filter basis. The collection of daytime neon fringe flats provides a fast, efficient method to produce fringe frames and the de-fringed CCD images show a complete removal of the night sky effects.

2. Fringing in Charge-Coupled Devices

Fringing most notably occurs within a CCD when near monochromatic light is incident on the detector. Spectroscopic observations are prone to fringing due to their collection of dispersed light placing individual wavelengths across pixels (e. g., Malumuth et al., 2003). Direct images also suffer from fringing (e.g., Gullixson 1992), especially for narrow band observations, primarily due to the bright night-sky emission lines from atmospheric OH molecules. Auroral [OI] emission near 630 nm can also be strong at times and partake in fringe production. Reducing fringing in a CCD can be done by controlling the CCD thinning process to a high level of flatness and by applying an anti-reflection coating to the back of a thinned CCD. Both of these solutions provide mitigation by reducing the fringe amplitude from near 50% or more to 2% or less.

Correcting for fringes in near-IR CCD images during the reduction process is, in principle, not hard but often takes valuable observing time to obtain a good fringe frame to use for calibration. Dome flats or twilight flat fields will not contain fringes as they are illuminated by polychromatic light from the flat-field lamps or the setting (rising) sun. Observers typically depend on observatory archive fringe frames or produce fringe images themselves using a large number of deep exposures taken during the night (e.g., Tyson 1990). These dithered exposures are then medianed together to remove the stars and combined to provide a supersky flat (hopefully) containing the fringe pattern of the CCD that can then be used for fringe removal (Gullixson 1992).

Producing a night time fringe frame is a time consuming procedure both at the telescope

²<http://www.noao.edu/kpno/mosaic/mosaic.html>

(taking valuable observing time) and in the reduction process (combining the images) and often only produces a low quality, low S/N fringe calibration image. In addition, the OH emission lines responsible for the near-IR fringing are particularly troublesome as their intensity can change randomly and rapidly throughout a night and can even show periods of zero intensity, perhaps during the time period when the sky flats are being obtained.

Figure 1 shows the night sky spectrum from 650 to 930 nm (Massey and Foltz 2000) and illustrates the large contribution to the sky flux from OH emission bands. For a given filter such as I or z, numerous, essentially monochromatic emission lines combine to cause the CCD fringing.

The shape and spacing of a CCD fringe pattern is dominated by thickness variations of the CCD substrate itself. The variations are not uniform and lead to a fringe pattern which is only semi-regular in spacing, shape, and interference band width. The wavelengths of the emission lines present within a bandpass account for the width of the alternating fringe pattern which would be nicely regular if the CCD thickness variation was extremely uniform. The thickness variation needed for a single fringe to occur, Δt is given by (Janesick 2000)

$$\Delta t = \frac{\phi \lambda \cos \theta}{4\pi n}$$

where ϕ is the phase difference needed for interference (2π), λ is the wavelength of light, θ is the angle of incidence (assumed to be normal), and n is the index of refraction of silicon taken to be constant for our purposes with a value of 3.6³. Using the I bandpass as an example, the change in CCD thickness between where a fringe at 750 nm will occur versus one at 900 nm is 0.021 microns. For a typical modern thinned CCD (such as the e2v device) the thickness variation over ~ 2048 pixels will be about 1 micron. If this were a uniform thickness change, say from the center to the edge of the CCD, the observed fringe separation at these two emission line wavelengths would be ~ 40 pixels. Given that there are OH emission lines covering the entire I (and R and z) bandpass, the fringes from each individual line blend together and produce bright and dark bands, each roughly 40 pixels wide. Thus, the OH emission lines produce, for practical purposes, a single broad fringe pattern on the image consisting of many blended fringes from the various emission lines, each of which is offset by a small fraction of a pixel (~ 0.05 pixels for $\Delta\lambda=50$ Å). Therefore, the average fringe pattern produced on a CCD image by the summation of all the OH emission lines within a given bandpass can be well approximated by essentially any set of emission lines that generally have the same wavelength distribution with a given bandpass.

3. Neon Lamp Flat Field Images

Since any set of emission lines covering a bandpass will provide the same fringe pattern for a given filter and CCD combination, we examined the use of a neon lamp as a source to provide a

³<http://www.pveducation.org/pvcdrom/appendicies/optical-properties-of-silicon>

fringe image. The spectrum of a neon lamp in the near-IR is shown in Fig. 1 where it can be seen to provide a similar emission line distribution pattern to that of OH within the filters of concern.

A neon lamp test fixture was attached to the front end of the Kitt Peak 4-m Mayall telescope during the commissioning run of the Mosaic 1.1 wide-field imaging camera. Since Mosaic 1.1 is a prime focus instrument, the top of the secondary tube was closed and provided a nice mounting surface for our neon paddle lamp (Fig 2). The telescope was then pointed at the flat field screen mounted inside the dome, the neon lamp alone illuminated the flat field screen, and several trial neon fringe flat exposures were obtained. In our case, 180 sec exposure times provided high S/N fringe flat images in R, I, and z bandpasses with our I band neon flat image shown in Fig. 3. The neon lamp images were obtained during the afternoon with the dome closed using a process identical to the method used to obtain dome flats. The neon fringe flats were then used as fringe frames during the image reduction and calibration process.

4. Defringing

Mosaic 1.1 images of a star field were obtained in I and z band on a night when fringing due to OH was readily apparent. The level of the fringing in the I band image amounts to a 2-3% modulation, increasing to near 5% in z band for these same CCDs. A similar amplitude increase was observed in the fringe level between I and z bands in the Gemini-N GMOS e2v DD CCDs (Hook et al., 2004). Comparison of the fringes in the neon fringe flat to those caused by OH emission in the I band star field image, show an identical pattern of interference bands modulated by the CCD thickness variations (Fig. 4). In addition, we note that both fringe patterns show interference bands with semi-regular spacing near 40 pixels. This match in fringe pattern is to be expected as both sources produce a set of emission lines covering the I bandpass.

Following the usual image reduction process (e.g., Newberry 1991; Gullixson 1992; Howell 2006) and using the neon fringe flat field to defringe the star image, the final image shows a complete removal of the night sky fringe pattern (Fig 4). Examination of an average row plot across the raw image and the same region of the final image is presented in Fig. 5. We see here the 2-3% fringing present in the raw I band image due to the OH night sky emission lines. After reduction, the fringe pattern has been completely removed (Fig. 5) and the image is well flattened. The high S/N neon fringe flat has served its purpose well and provided an easy calibration method for fringe removal.

5. Conclusion

We presented an easy and efficient method to provide a high S/N fringe frame using a neon lamp to illuminate a flat field screen inside a dome. Observations of this illuminated screen, taken in a similar manner to normal flat field exposures, can be accomplished during the day obviating

the need to use valuable time during the night to produce a supersky frame. The fringe pattern produced by neon, or essentially any set of similarly distributed emission lines within a given bandpass, is identical to that produced by night sky OH emission and therefore can be used to fringe correct astronomical images of interest. Images containing fringes and corrected using neon fringe flats show complete fringe removal as well as good flatness leading to high photometric quality.

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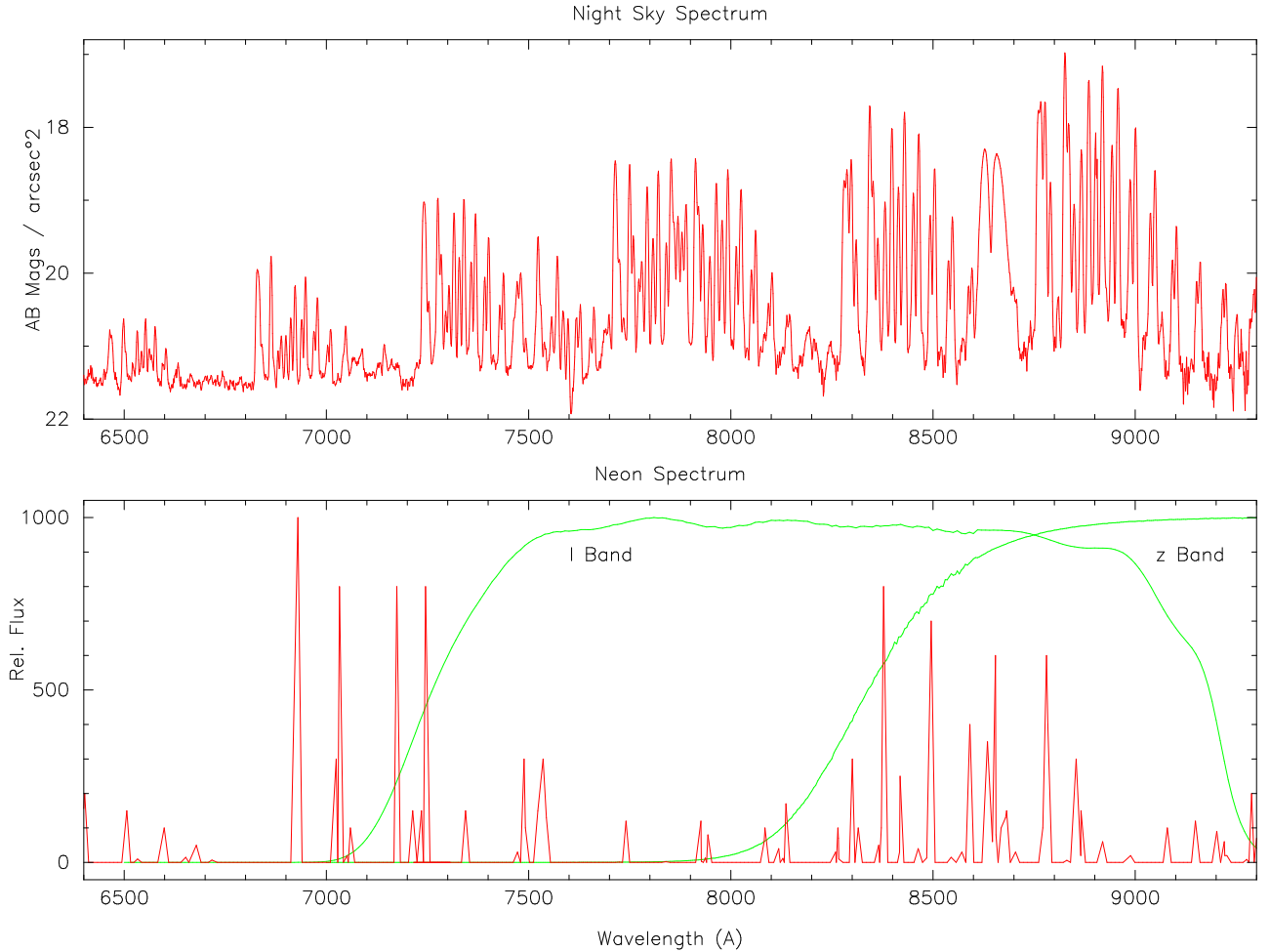


Fig. 1.— Top: Spectrum of the night sky covering the near-IR (Massey & Foltz 2000). Notice the large emission line bands due to the OH molecule in the Earth’s atmosphere. These emission lines are the primary cause of CCD fringing. Bottom: Emission line spectrum of a neon lamp shown over the same spectral region. Neon also has groups of emission lines within this region which will provide the same fringe pattern on a CCD as OH emission. Broadband I and z bandpasses discussed in this paper are indicated.



Fig. 2.— Photograph of the neon “flat field” paddle lamp attached to the front end of the secondary tube on the Kitt Peak 4-m Mayall telescope. This temporary configuration was used to obtain dome flats with the neon light source illuminating the flat field screen mounted on the inside of the 4-m dome.

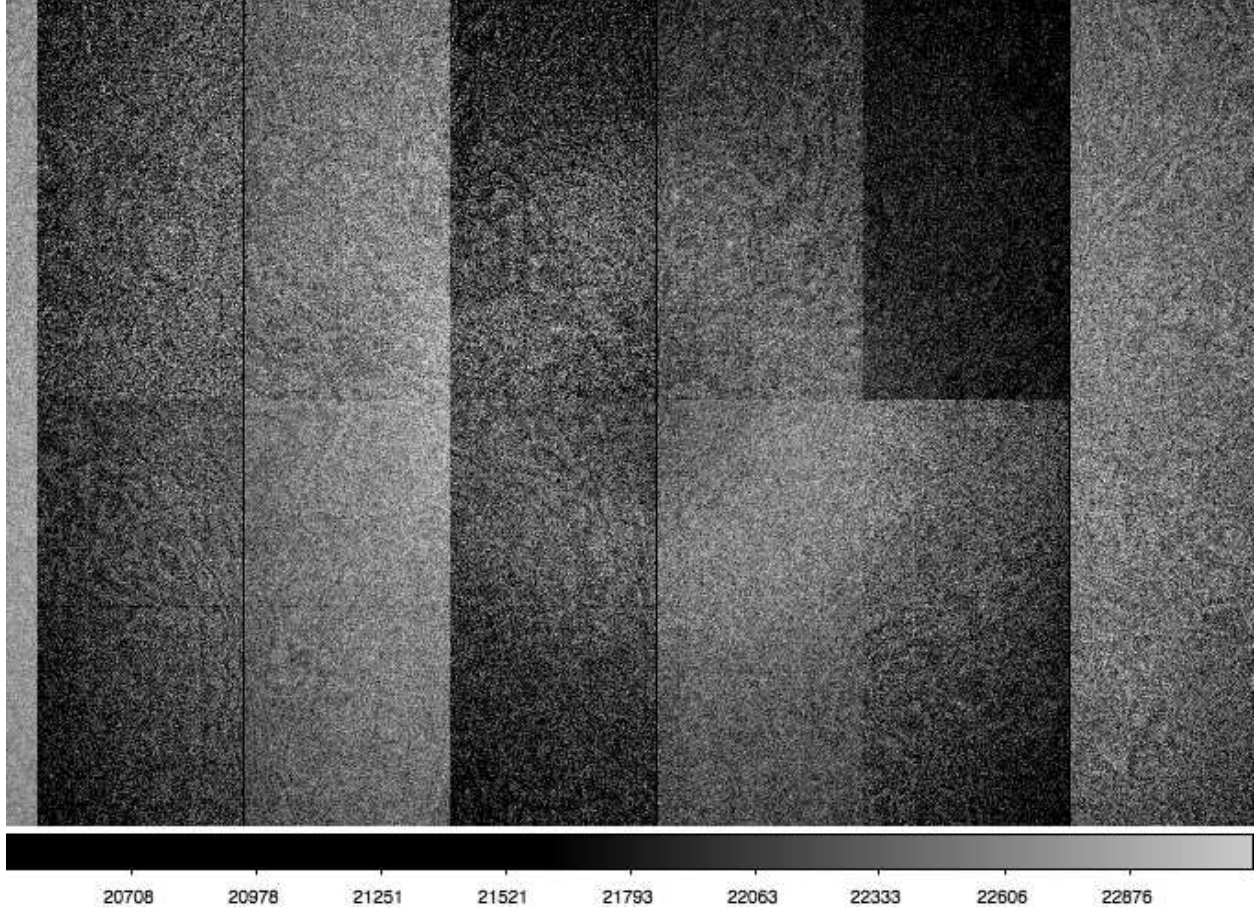


Fig. 3.— The central six CCDs of the Mosaic 1.1 I band neon fringe flat field. This 180 second exposure shows a raw image where the 12 amplifiers (2 per e2v CCD) are visible due to their slightly different bias levels, the pupil ghost at the image center, and the strong fringing due to the neon emission lines in the flat field.

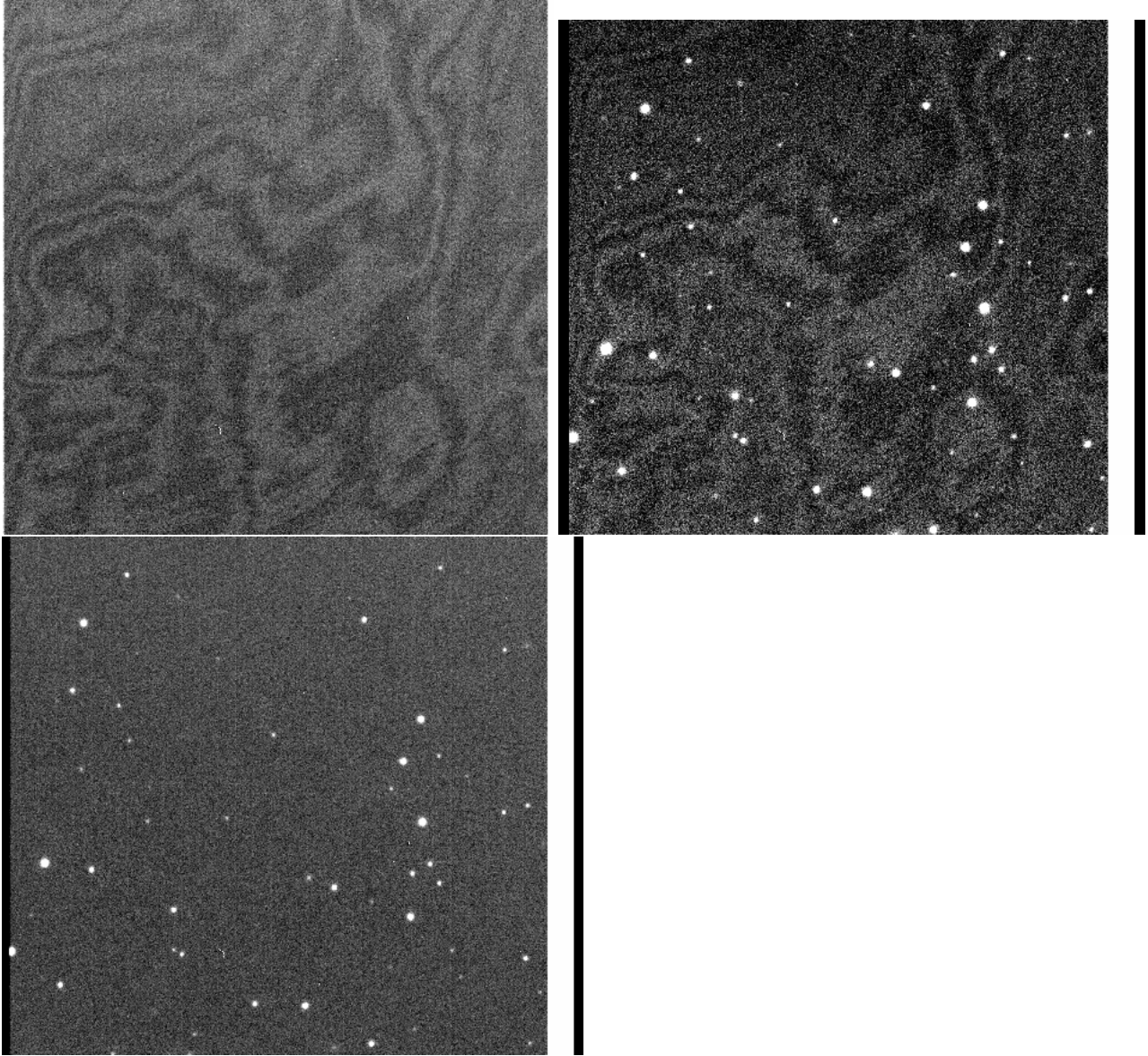


Fig. 4.— A 1024 X 1024 portion of one of the Mosaic 1.1 CCDs showing (TOP) the I band neon fringe flat field, (MIDDLE) the same CCD section showing a night time I band image of a star field taken with strong OH emission, and (BOTTOM) the same section in the final reduced image showing the complete removal of the CCD fringes. Note that the fringe pattern is the same in the I band neon fringe flat image and the I band night sky image.

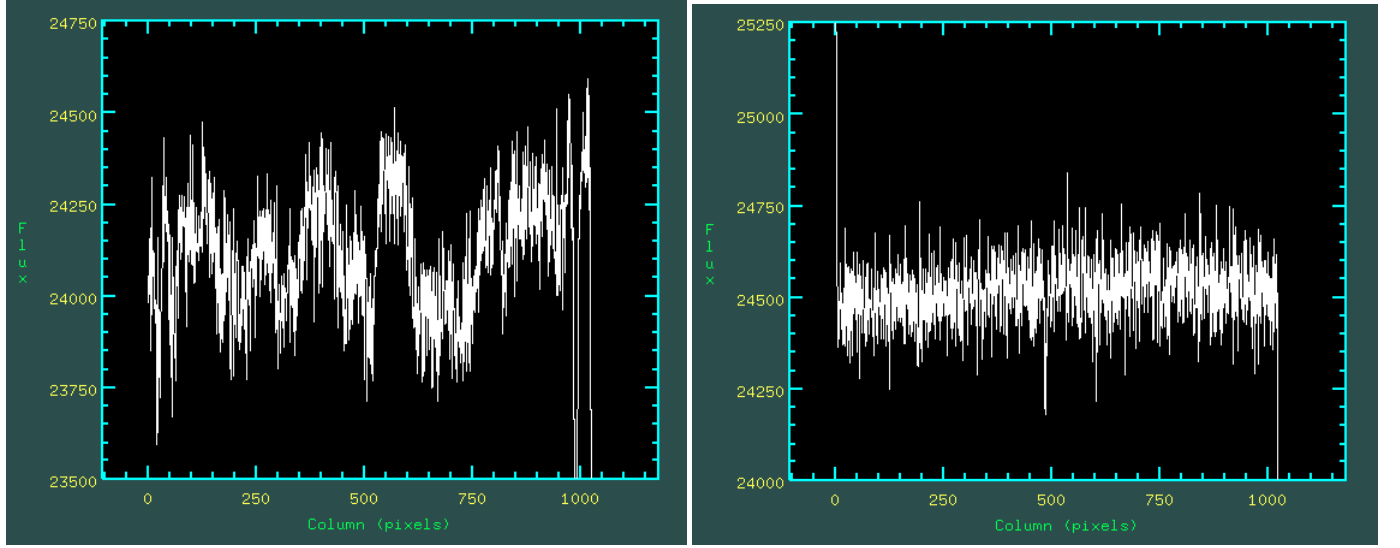


Fig. 5.— Left: A plot of 20 averaged columns across the I band star field image shown in Fig. 4. The fringes in the raw image are obvious and have peak-to-peak amplitudes of 2-3% (about 500 ADU) and interference spacings near 40-50 pixels. Right: The same column average plotted after defringing the image using the neon lamp flat field. The fringes have been completely compensated for.